Analysis and evaluation of a traffic light control system simulation model using the NetLogo platform

Phân tích và đánh giá mô hình mô phỏng hệ thống điều khiển đèn giao thông sử dụng nền tảng NetLogo

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Abstract

With the rapid development of means of transport today in big cities in Vietnam and developing countries around the world,, traditional urban traffic light control systems cannot allocate traffic light cycle times at intersections optimally, causing traffic congestion to become increasingly serious. With the support of Netlogo software, on the basis of multi-agent modeling, we have built an optimal simulation model of light cycle time for the problem of balancing actual traffic volume and cycle time lights at traffic intersections. We use the optimal light cycle length algorithm to calculate the traffic light cycle time within the most suitable range. The traffic flow at the intersection is set manually, thereby analyzing the effectiveness of the traffic light cycle time with the traffic flow. A loop to vary the traffic light cycle time within a reasonable computational range was applied. The final result is that, through the simulation model, traffic light cycle times can be optimally and flexibly adjusted to different traffic flows.

Keywords: Traffic lights, multi-agent system, Netlogo, control system optimization.

Tóm tắt

Với sự phát triển nhanh chóng của các phương tiện giao thông hiện nay tại các thành phố lớn ở Việt Nam và các nước đang phát triển trên thế giới, hệ thống điều khiển đèn giao thông đô thị truyền thống không thể phân bổ thời gian chu kỳ đèn giao thông tại các nút giao một cách tối ưu, khiến tình trạng tắc nghẽn giao thông ngày càng nghiêm trọng. Với sự hỗ trợ của phần mềm Netlogo, trên cơ sở mô hình hóa đa tác tử, chúng tôi đã xây dựng được mô hình mô phỏng tối ưu thời gian chu kỳ đèn cho bài toán cân bằng giữa lưu lượng giao thông thực tế và thời gian chu kỳ đèn tại các nút giao thông. Chúng tôi sử dụng thuật toán độ dài chu kỳ đèn tối ưu để tính toán thời gian chu kỳ đèn giao thông trong phạm vi phù hợp nhất. Lưu lượng giao thông tại nút giao được thiết lập thủ công, qua đó phân tích hiệu quả của thời gian chu kỳ đèn giao thông với lưu lượng giao thông. Một vòng lặp để thay đổi thời gian chu kỳ đèn giao thông trong phạm vi tính toán hợp lý đã được áp dụng. Kết quả cuối cùng là thông qua mô hình mô phỏng, thời gian chu kỳ đèn giao thông có thể được điều chỉnh tối ưu và linh hoạt theo các luồng giao thông khác nhau.

Từ khóa: Đèn giao thông, hệ thống đa tác nhân, Netlogo, tối ưu hóa hệ thống điều khiển.

1. Introduction

Intelligent transportation has emerged as a hallmark of the contemporary urbanization process. The rising quantity of vehicles significantly contributes to the escalating urban traffic congestion in Vietnam and other developing nations, diminishing travel efficiency and prompting the development of smart transportation solutions. Urban road traffic congestion is attributable to various factors, including the proliferation of automobiles, inadequate urban road infrastructure, and inflexible traffic signal timing at intersections (Zou et al., 2019). These issues have significantly impacted individuals' everyday commutes and urban development. Urban transportation congestion has emerged as a critical issue that cities must rapidly address. Urban traffic light control is an effective strategy to alter urban road traffic conditions, enhance vehicle operational efficiency, and decrease traffic light wait times. The existing urban traffic system is marked by complexity and irrationality, leading to numerous emergency situations, which complicates the development of an effective and rational simulation model (Liu & Rastgoftar, 2022; Uppaluru et al., 2022). In the developing nations, fixed traffic light timing is a significant barrier to the implementation of intelligent urban transportation, negatively impacting people's lives and placing additional strain on urban roads.

Traffic researchers both domestically and internationally have suggested numerous solutions for conventional and intelligent traffic light management. Scholar Xu Cheng proposed a solution to segment the day into multiple time intervals, reflecting the substantial variations in traffic volume throughout the day, and to apply distinct regulations for each interval (Xu, 2020). This research method has numerous limitations and is applicable only to specific scenarios, such as when the traffic volume at an intersection remains constant, which is evidently unsuitable for the variability of urban road traffic. A state of paralysis will ensue, resulting in traffic congestion or direct collisions. Conventional solutions fail to fully utilize the flexibility and efficiency of traffic signals.

In 2010, Thong conducted a study on the dynamic control method for traffic lights, utilizing the theory of hedge algebra. This solution uses a dynamic programming method and integrates algorithms into the calculation of traffic light cycle time, increasing efficiency compared to fixed light cycles and making the traffic light control system more flexible and versatile (Thong, 2010). Pham Duy Duong and his colleagues have studied and proposed an intelligent control solution for traffic lights systems using PLC S7-1200. This study employs the PLC S7-11200 controller, along with an algorithm for cycle and signal phasing optimization, in Matlab to construct the control interface and successfully test four traffic light models (Pham et al., 2017). On the basis of a fuzzy inference algorithm, Li Hong proposed an intelligent traffic light system (Li, 2013). Using the concept of dynamic programming, he separated all of the city's roads into numerous sub-roads, connected them with nearby roads, and finished the traffic light planning for the entire city by connecting the sub-roads with a coordinated control system. In 2015, Cao Nguyen Khoa Nam and colleagues studied applying wireless sensor network to control and supervise traffic light node controllers (Cao et al., 2016). Kartikasari et al. studied traffic light control optimization using Sugeno fuzzy logic method, the study calculated the optimal traffic light duration by applying fuzzy logic at intersections, by inputting the density of each lane in the intersection (Kartikasari et al., 2020). In 2018, Deng et al. proposed an intelligent traffic light system utilizing fuzzy inference rules, which compares the disparity between the number of vehicles awaiting the red light phase and those waiting during the green light phase across various road segments as input variables to optimize green light durations (Deng & He, 2018). The duration of the green light serves as an output to deduce the green light duration for each lane. In 2020, Yao and colleagues introduced a machine learning approach to oversee and regulate the traffic light system functioning within an iterative framework (Yao & Song, 2020). Each day is segmented into various time periods based on distinct traffic flows, and the traffic volume for each period is subsequently recorded. Utilize iterative learning control to determine the optimal traffic signal duration for the present roadway segment.

Simulation methods are extensively utilized in the analysis and optimization of traffic light control systems. In which, the simple and intelligent Netlogo simulation platform serves as a powerful tool for simulating and optimizing traffic control system problems. From a simulation standpoint, modeling and simulating intricate urban routes is an excellent method for optimizing time and traffic flow rate. Agents are represented as vehicles engaged in traffic, with urban roads and vehicle operating conditions simulated using Netlogo's simulation platform. Each agent is given intelligent characteristics that are comparable to those of traffic participants, and they will function in a virtual setting, producing appropriate and useful data for study and examination.

While developed countries have developed and implemented numerous intelligent traffic light control systems that aid in reducing traffic congestion, some of these systems have relatively complex and expensive algorithms for controlling traffic light timing. With the current difficult technical and economic conditions in Vietnam, the application and implementation will still take a long time.

This paper proposes a simple traffic light control system that manually sets the number of vehicles on the simulation platform, changes the traffic light on time in real time based on the level of road traffic congestion, and selects the best solution after repeated testing.

2. Research methods

The paper sets the vehicle properties in the Netlogo simulation software and sets the number of different vehicles, and then calculates the traffic light time within a reasonable range through the optimal cycle length formula. We choose to use Netlogo simulation platform to simulate various emergency situations when vehicles pass through the intersection, and record the data in time, and by continuously comparing and processing the data, minimize the average waiting time of vehicles. Because in practice, most urban traffic is simple basic intersections, so this paper chose the simplest intersection to simulate in order to bring clarity and accuracy to the model.

3. Simulation model of intelligent traffic light control system using Netlogo

This paper uses the Netlogo simulation platform to model intersections and vehicular operations on urban roads, analyze the average waiting time of vehicles in various environments, and optimize traffic light timing to minimize average waiting durations. The Iterative Learning Control method is utilized to address issues such as prolonged waiting times on conventional traffic routes, ensuring that vehicles experience unobstructed flow and operate efficiently.

3.1 Algorithm for establishing the optimal length of lamp cycles

The formula for determining the optimal length of the light cycle is as follows:

$$\begin{cases} C_0 = \frac{(1.5L+5)}{(1-Y)} \\ L = \sum_i (l + I - A) \end{cases} \tag{1}$$

Where: C_0 is the light cycle length, L is the lost time, l is the wasted time during the start-up process, A is the yellow light time, I is the time interval, i is the number of phases and Y is the traffic flow rate, and Y is calculated by formula (2). Yi represents the critical flow rate of phase i, qi represents the traffic flow of phase i and Si is the critical saturation flow of phase i.

$$\begin{cases} Y = \sum_{i=1}^{n} Y_i \\ Y_i = \frac{q_i}{s_i} \end{cases} \tag{2}$$

The duration of the traffic light cycle must be maintained within a reasonable range (Zhang & Dong, 2011). A reduced light cycle time substantially enhances traffic capacity and alleviates traffic congestion. When the light cycle surpasses 150 seconds, traffic capacity cannot be significantly enhanced, and delay time will increase. The light cycle duration should not be excessively brief. A brief cycle may impede the safe passage of pedestrians and vehicles through the intersection, potentially leading to traffic accidents. Consequently, the parameters of the light cycle must be distinctly delineated. The typical duration of the light cycle ranges from 45 to 150.

3.2 Building an intelligent traffic light control model using Netlogo

The intelligent traffic light control system model built on the Netlogo platform is divided into three steps: the agent definition phase, the agent rules simulation stept, and finally the verification and calibration stept. The diagram for building an intelligent traffic light control model on the NetLogo is shown in Figure 1

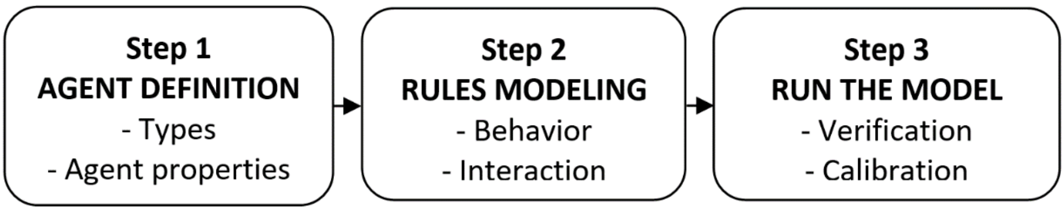


Figure 1. The diagram building a traffic light control model on the NetLogo

In the agent definition step, based on the behavioral and functional characteristics of the entities in the traffic light control model, the turtle agent is specifically modeled into two types: vehicles and traffic lights. The simulated patch is an urban road. The vehicle agent determines its position by interacting with the urban road to determine its driving state, such as whether it can turn or not. The interactions between agents are divided into two types: one is the interaction between vehicles, and the other is the interaction between vehicles and traffic lights.

In the rules modeling step, we model the behavior and interactions of agents based on rules. The interaction between vehicles causes them to adjust their speed. If the vehicle behind is faster than the one in front, it will decide whether to pass. If not, it will automatically reduce its speed. When the vehicle in front reaches zero speed and the vehicle behind is in a waiting state, the vehicle's current speed also decreases to zero. Vehicles and traffic lights interact with each other When the vehicle passes through an intersection, the traffic light will make a reasonable judgment. When the light is red, the speed is set to 0, and when the light is green, the vehicle can pass that section of the road. Using Netlogo language to encode the correlations between the components in the model, the traffic light cycle time is obtained by applying the optimal cycle length formula (1) to further achieve a reasonable traffic light cycle time range at the intersection in the actual situation. Traffic intersection simulation model is shown in Figure 1:

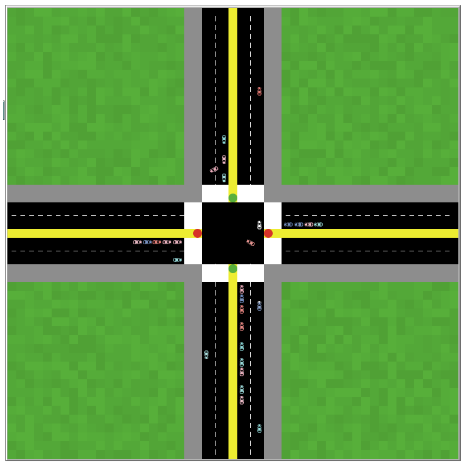


Figure 1. Traffic intersection simulation model

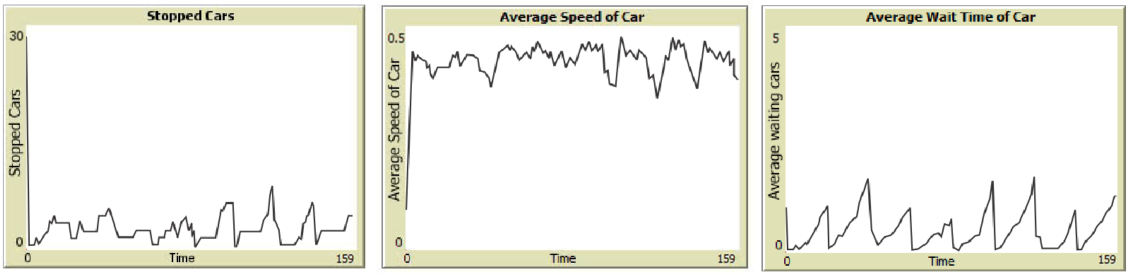
Control buttons, intersection displays, and graphs make up the model interface. You can adjust the number of cars appearing in the interface by using the "number of cars" feature. Additionally, you can use the "current-auto" feature to automatically adjust the traffic light changes at the current intersection. The "ticks per cycle" slider adjusts the dynamic change cycle of the traffic lights. The vehicle's max-speed limit is 1.0. This is because the vehicle must look ahead at the speed limit to determine if there is a car ahead; if not, it speeds up, and if there is, it slows down. The Change light button controls the traffic light change at the intersection at any time, which is often used when traffic jams occur. The Setup button resets all variables. The Go button starts the model run.

In the verification and calibration stept are performed simultaneously to confirm the validity and accuracy of the model behaviors. Model analysis shows that when there are few vehicles passing through the intersection and no traffic lights to block the waiting vehicles, the average waiting time and average speed of the vehicles are significantly lower than when there are traffic lights. For example, if there is only one vehicle and no traffic lights, driving is convenient; with traffic lights, you have to wait. However, as the number of cars increases, the benefits of having traffic lights become more and more obvious. Traffic lights help maintain order on the road. Therefore, a fixed traffic light cycle will lead to less waiting time wasted for vehicles. Smart traffic lights can effectively avoid this problem.

4. Results

To evaluate the benefits of intelligent traffic light control, this paper uses the Netlogo platform to simulate the state of vehicles passing through the intersection, record the generated data, and compare the generated data in the model with each other. We obtain data in two scenarios.

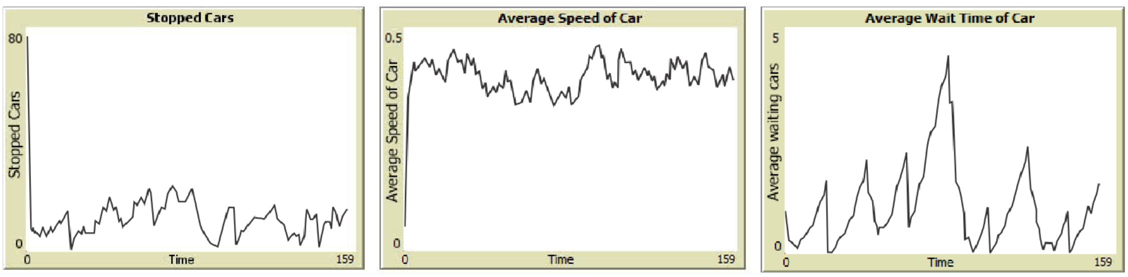
Scenario 1 uses a traffic light control system with fixed light times. Analysis and evaluation with different traffic volumes. In the case of a low and high number of vehicles, Figures 2 and 3 respectively describe the vehicles waiting at traffic lights at intersections, the average speed, and the average waiting time.



(a) (b) (c)

Figure 2. Scenario that there are not many cars at the intersection.

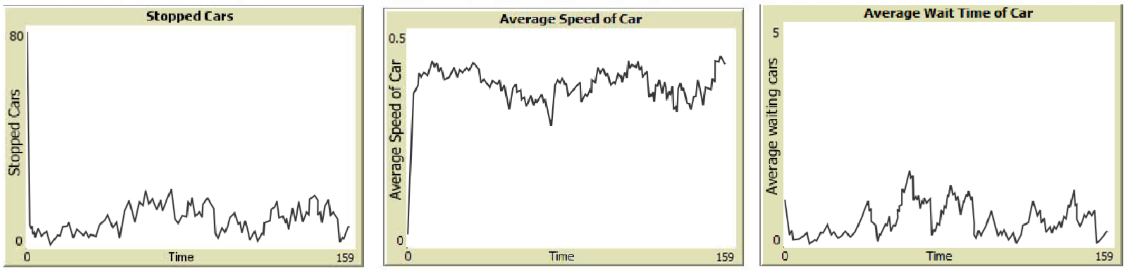
Graph (c) of Figures 2 and 3 reveals a significant change in the average waiting time of vehicles passing through the intersection when the traffic light time remains unchanged; an increase in the number of vehicles also results in a longer average waiting time. Therefore, when there are more vehicles in circulation, it is necessary to change the operating time of traffic lights to reduce the average waiting time of vehicles.



(a) (b) (c)

Figure 3. Scenario with a large number of vehicles at intersection

Scenario 2 used an intelligent traffic light control system. Figure 4 illustrates a scenario where numerous vehicles are equipped with smart traffic lights.



(a) (b) (c)

Figure 4. Scenario of using smart traffic lights with a large number of vehicles at intersection

In figure 4, we use the method of changing the smart traffic light cycle time. We can see from the graph (a), (b), (c) of figures 3 and 4 that the implementation of the smart traffic light cycle significantly reduces the average waiting time, particularly in situations where many vehicles are passing through the intersection. The average speed of the vehicle and the number of vehicles stopping at the intersection in both scenarios were basically maintained at a stable level.

5. Conclusions

This paper uses the Netlogo platform to simulate the most common intersections on urban roads, uses the optimal cycle length formula to find the most suitable traffic light cycle time within a reasonable range, applies it to different situations, uses data comparison, and finally finds the reasonable traffic light cycle time in different situations, which greatly reduces the average waiting time of vehicles passing through the intersection. Compared with the fixed traffic light time on daily roads, this research has brought convenience to people's daily lives. However, the scope of application of this paper has certain limitations, which are primarily reflected in two aspects: (1) This paper solely focuses on simple intersections, neglecting complex intersections and left-turn traffic lights. Therefore, future research models should take this into account and optimize it. (2) This model can only be effective at individual intersections, without connections between neighboring intersections and between intersections and connecting routes. Therefore, in the upcoming work, we will further enhance the model's application by coordinating traffic light control between neighboring intersections, as well as between the traffic light control system and connecting routes, using traffic data from those connecting routes.

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